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(54) **IRIS IMAGING TELEPHONE SECURITY MODULE AND METHOD**

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(52) **U.S. Cl.** .................. **382/117**; 340/5.82; 379/93.03; 382/115; 455/411

(58) **Field of Search** ................................ 382/115, 116, 382/117–118; 379/93.02, 93.03, 445; 380/247; 713/186; 455/410, 411; 340/5.8–5.83

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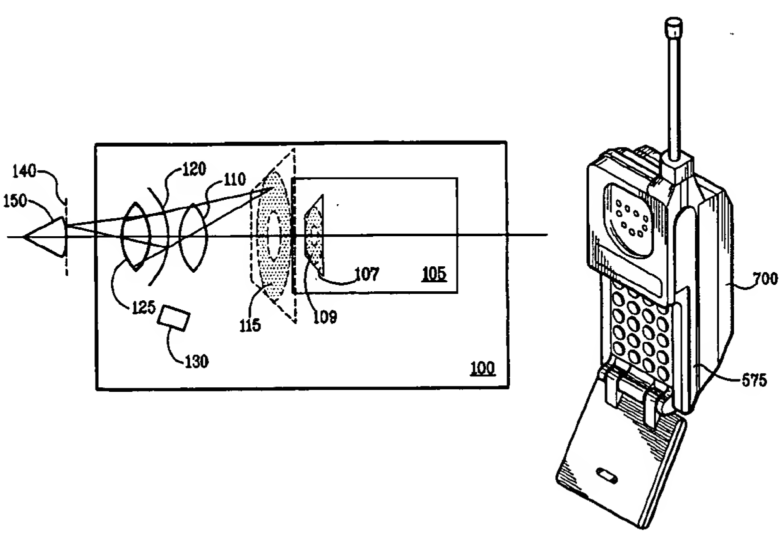
(57) **ABSTRACT**

A compact, handheld imaging apparatus which can be used to capture high-quality iris images for identification of a person. The handheld iris imager is non-invasive and non-contacting and comprises a camera, a cold mirror, a lens, and an illuminator. The imager has sensors and indicators which assist a user in aligning and focusing the device. The imager also automatically captures the image when proper positioning is achieved. A template of the image is then compared to a database of previously stored templates of images to identify the person. The imager is integrated into a telephone as a security module. The telephone cannot be unlocked and used unless a user has been identified and authorized by the imager.

**33 Claims, 6 Drawing Sheets**



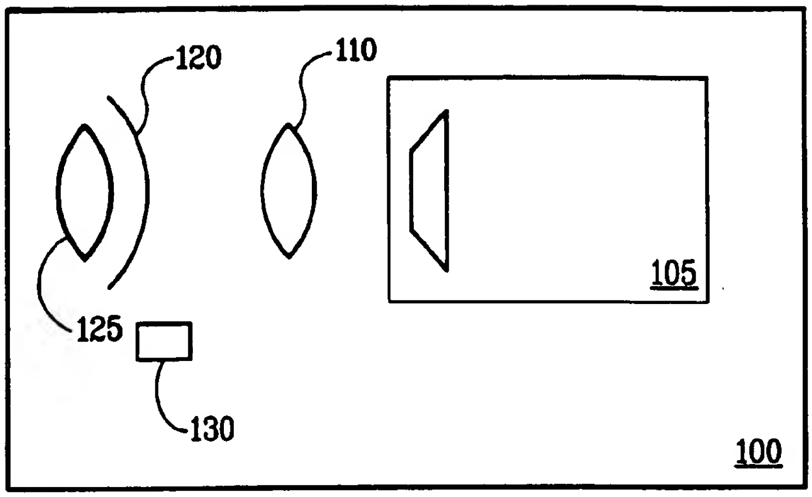

120
110
105
125
130
100

FIG. 1

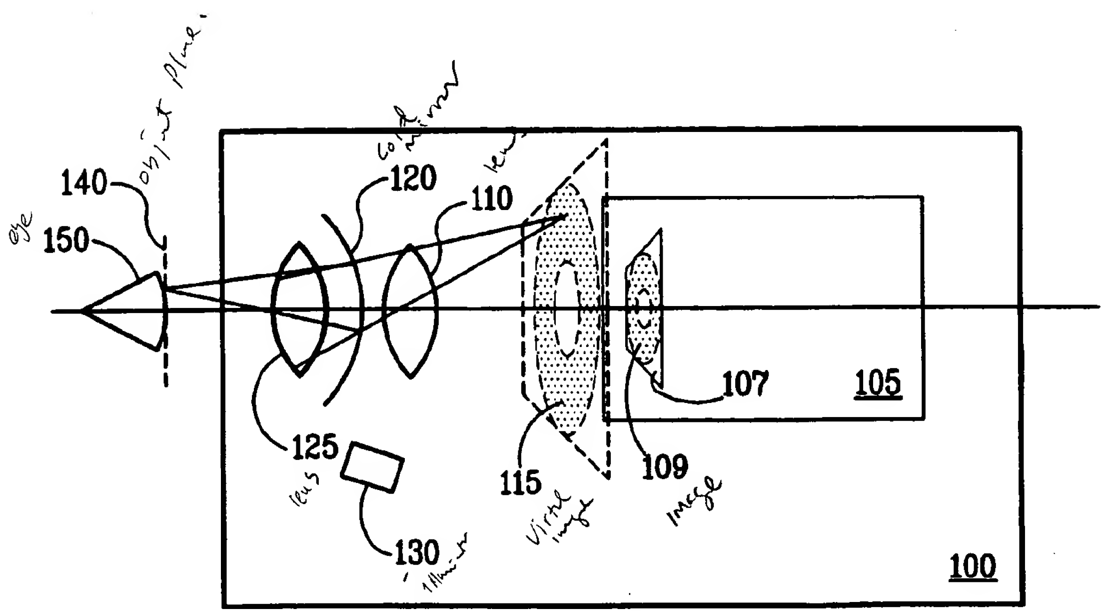

140
150
120
110
107
105
125
115
109
130
100
eye
lens
image

FIG. 2A

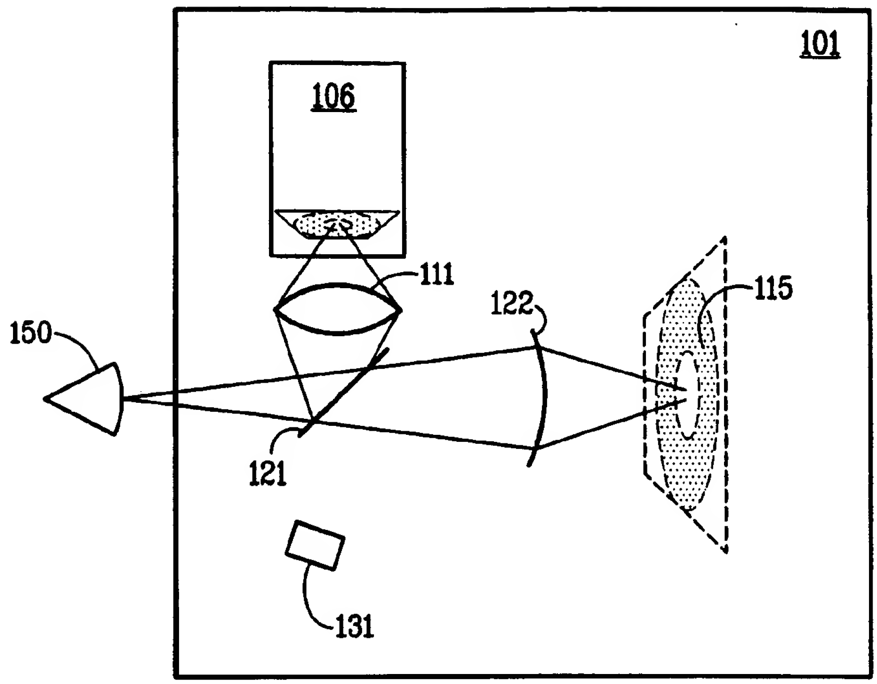

101
106
111
122
115
150
121
131

FIG. 2B

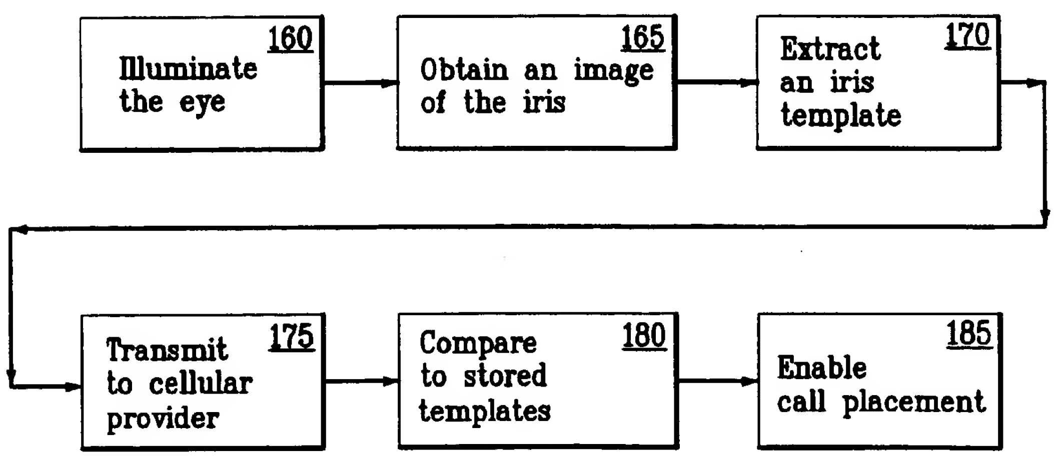

160
Illuminate the eye
165
Obtain an image of the iris
170
Extract an iris template
175
Transmit to cellular provider
180
Compare to stored templates
185
Enable call placement

FIG. 3

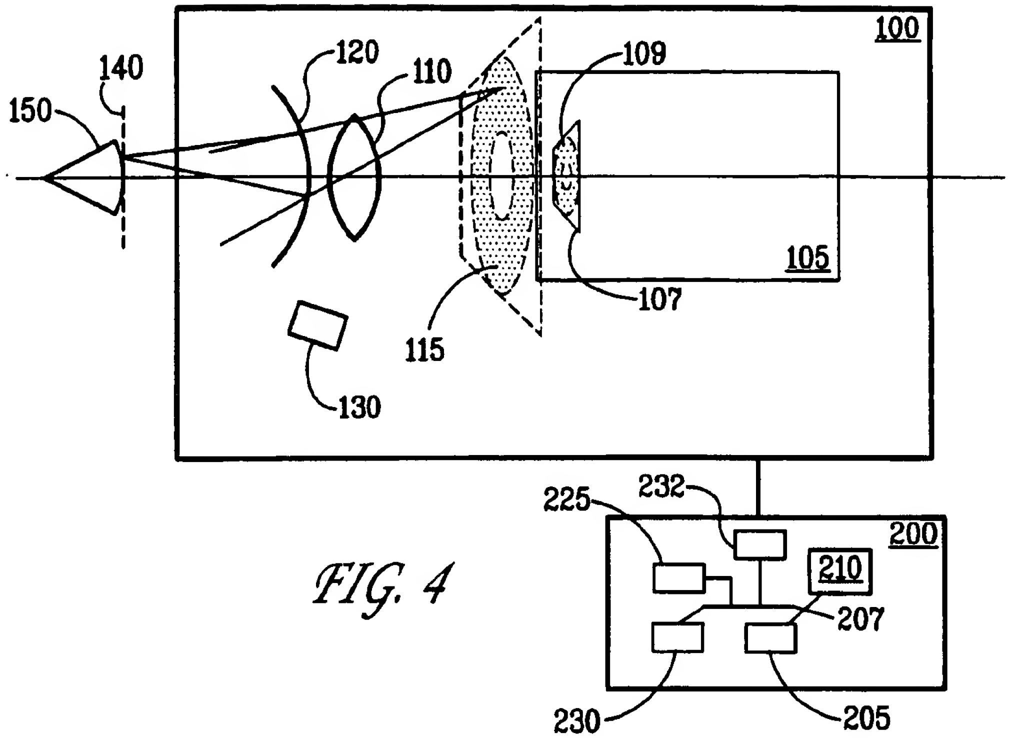

100
150
140
120
110
109
105
107
115
130
225
232
200
210
207
230
205

FIG. 4

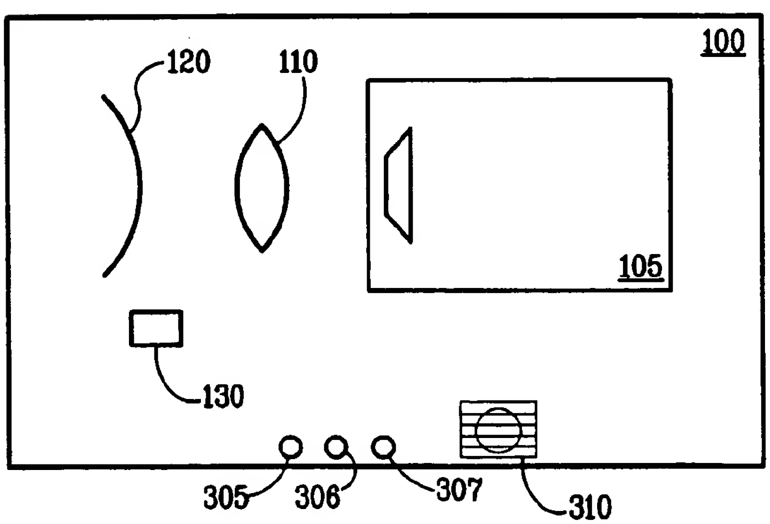

100
120
110
105
130
305
306
307
310

FIG. 5

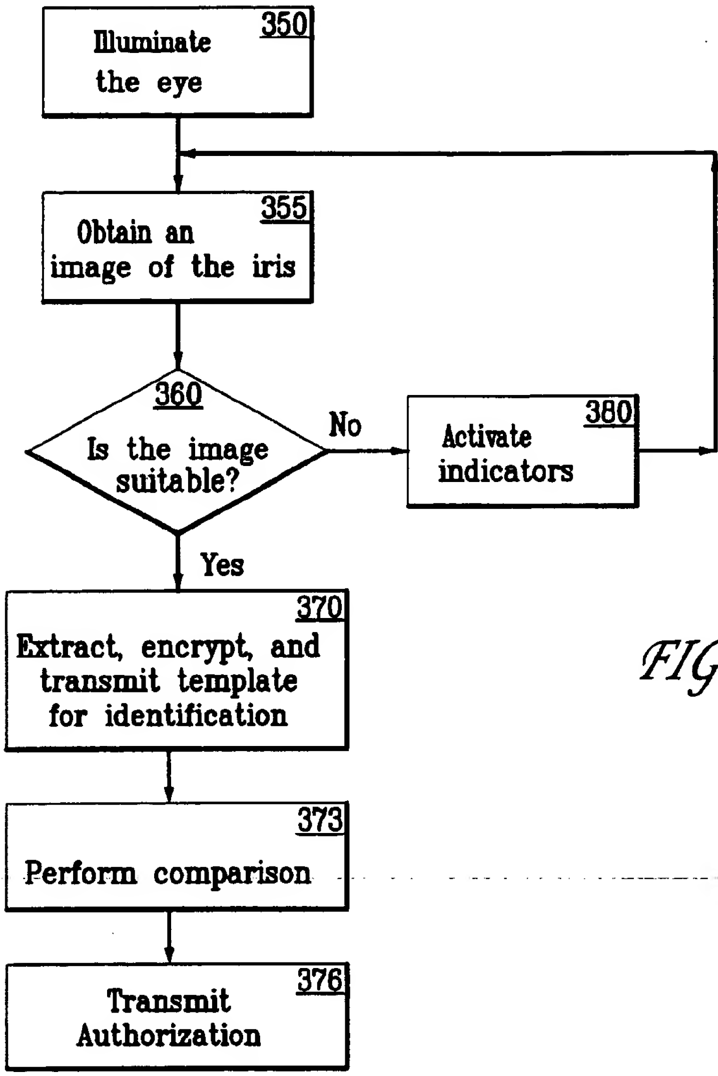

350
Illuminate the eye
355
Obtain an image of the iris
360
Is the image suitable?
No
380
Activate indicators
Yes
370
Extract, encrypt, and transmit template for identification
373
Perform comparison
376
Transmit Authorization

FIG. 6

FIG. 7

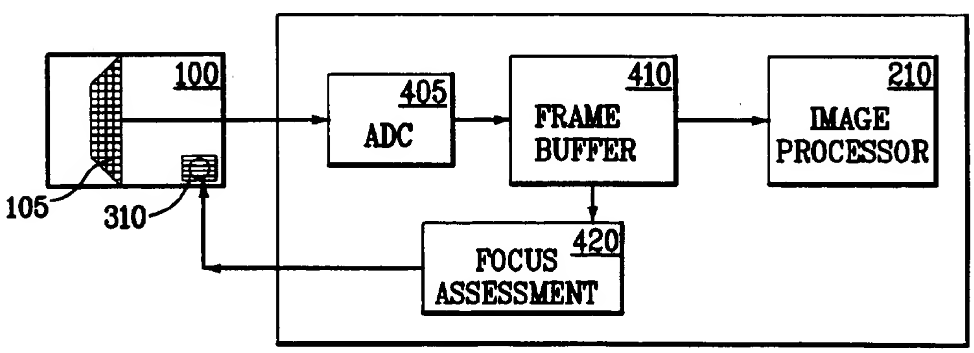
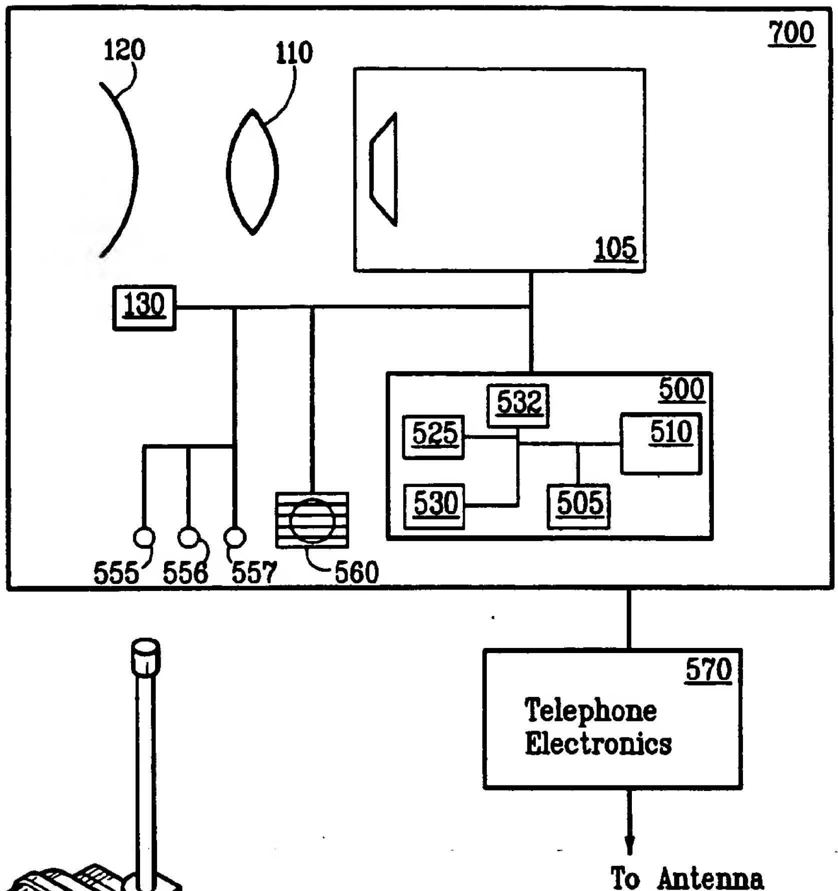

100
405
ADC
410
FRAME BUFFER
210
IMAGE PROCESSOR
420
FOCUS ASSESSMENT
105
310

FIG. 8


700
120
110
105
130
532
500
525
510
530
505
555
556
557
560
570
Telephone Electronics
To Antenna

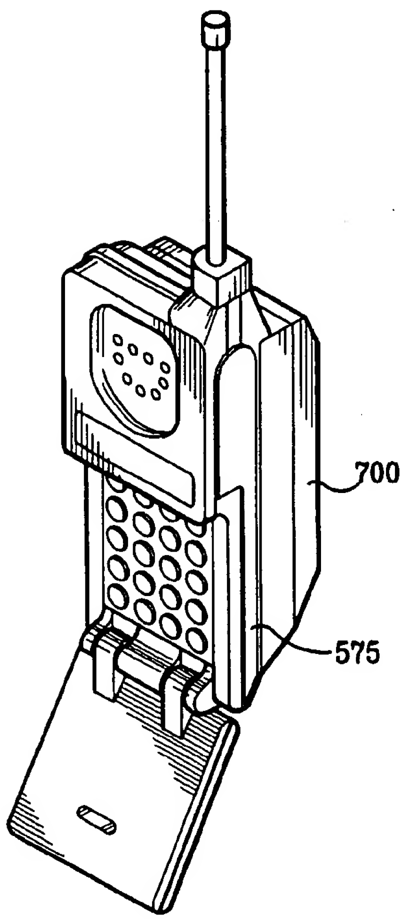
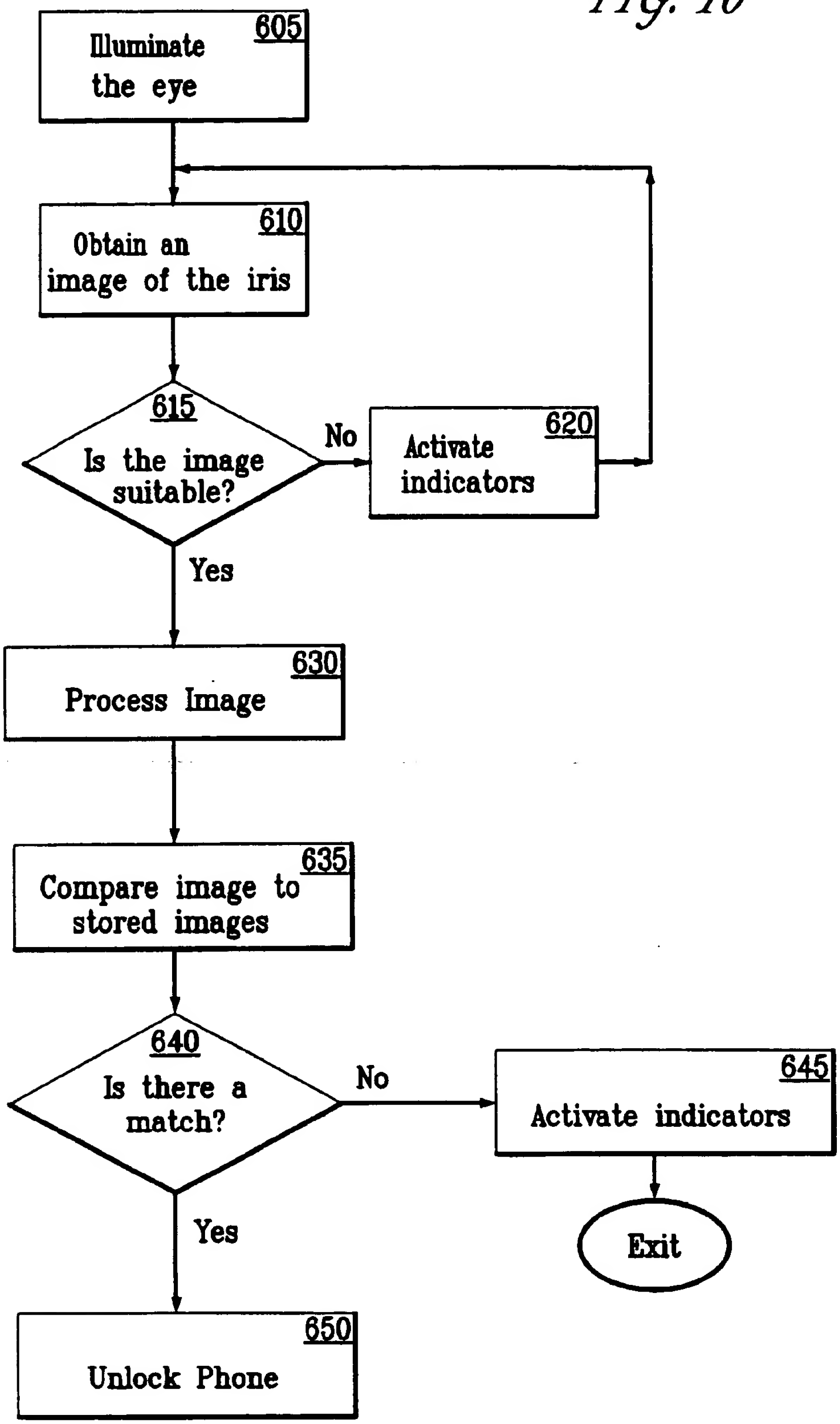

700
575

FIG. 9

FIG. 10


605
Illuminate the eye
610
Obtain an image of the iris
615
Is the image suitable?
No
620
Activate indicators
Yes
630
Process Image
635
Compare image to stored images
640
Is there a match?
No
645
Activate indicators
Exit
Yes
650
Unlock Phone

# IRIS IMAGING TELEPHONE SECURITY MODULE AND METHOD

## FIELD OF THE INVENTION

The present invention relates in general to identification of physical characteristics of a human being or other animal. More particularly, the present invention relates to iris recognition.

## BACKGROUND OF THE INVENTION

Various technologies are used for uniquely identifying a person in accordance with an examination of particular attributes of either the person's interior or exterior eye. One of these technologies involves the visual examination of the particular attributes of the exterior of the iris of at least one of the person's eyes. The iris of the human eye has random patterns of striations, ciliary processes, crypts, rings, furrows and other features which had been shown capable of generating highly unique biometric templates for personal identification. In this regard, reference is made to U.S. Pat. No. 4,641,349, "Iris Recognition System", issued to Flom et al., and U.S. Pat. No. 5,291,560, "Biometric Personal Identification System Based on Iris Analysis", issued to Daugman. As made clear by these patents, the visible texture of a person's iris can be used to distinguish one person from another with great accuracy. Thus, iris recognition can be used for such purposes as controlling access to a secure facility or a bank automatic teller machine, for example. An iris recognition system involves the use of an imager to video image the iris of each person attempting access, and image processing means for comparing this iris video image with a reference iris image on file in a database.

Iris identification systems have been developed that are capable of collecting images of the iris and processing them to produce biometric templates. These templates may be used to identify individual irises with extremely low error rates, on the order of 1 in $10^{78}$. The systems capture the iris images using stationary optical platforms that are often large, complex, and expensive. The systems are difficult to use with minimal cooperation of the subject being identified. As a result their usefulness in many applications is limited.

The cellular telephone industry each year loses an estimated $650 million to cellular fraud, principally due to cloning of cellular telephones. Cloning involves re-programning a phone's electronic serial number and telephone number to those stolen from a legitimate subscriber. To counteract cloning, some service providers have utilized personal authentication techniques such as personal identification numbers (PIN) or voice verification to verify that the authorized subscriber is using the phone. This is unreliable because PIN number can be stolen or forgotten, and voice verification messages may be recorded.

Although the art of human recognition systems is well developed, there remain some problems inherent in this technology, particularly the lack of an iris imager and security module suitable for integration into a cellular telephone, and the lack of a method for using biometric information for enabling access to the cellular network. Therefore, a need exists for a recognition system that overcomes the drawbacks of the prior art.

## SUMMARY OF THE INVENTION

The present invention is directed to a telephone security module comprising: iris acquisition means having a front surface for obtaining an image of an iris of an eye; a lens



having a image plane disposed in front of the front surface of the iris acquisition means; a mirror disposed on a side of the lens opposite the iris acquisition means; an illuminator disposed along a side of the mirror; a memory for storing an iris image obtained by the iris acquisition means; a processor for extracting a template from the stored iris image; and a communications interface for transmitting the template to a central station.

According to one aspect of the invention, the iris acquisition means comprises a camera, and the mirror is a cold mirror. The camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm. The mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

According to another aspect of the present invention, the illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, and the eye is out of contact with the iris imaging apparatus.

According to another aspect of the present invention, the module further comprises at least a visible indicator or an audible indicator to indicate when the image of the iris has been obtained. According to another aspect of the present invention, the module further comprises a focus assessment processor coupled to the visible indicator and/or the audible indicator.

According to another aspect of the present invention, the processor unlocks a telephone responsive to a signal received from the central station.

In a further embodiment within the scope of the present invention, a method of unlocking a telephone responsive to the identification of a person comprises the steps of: (a) storing image information of the iris of at least one person's eye; (b) illuminating an eye of an unidentified person having an iris; (c) obtaining an image of the iris of the unidentified person; (d) determining if the image is an image of sufficient quality for a step (f) of comparing; (e) repeating steps (b) through (d) until the image of sufficient quality is obtained; (f) comparing a template of the obtained image with the stored image information to identify the unidentified person; and (g) unlocking the telephone responsive to a result of the step of comparing. The stored image information used for identification can be a code or template extracted from the image, and the comparison can be performed at a central database maintained by a telephone service provider.

According to one aspect of the present invention, the method further comprises the step of activating an indicator if the image is of insufficient quality. The indicator is an audible indicator.

According to another aspect of the present invention, the method further comprises the step of activating an indicator if the image is of sufficient quality. The indicator is a visible indicator.

According to another aspect of the present invention, the method further comprises the step of activating an indicator responsive to the step of comparing. The indicator is a visible indicator.

In accordance with a further aspect of the present invention, the step of determining if the image is an image of sufficient quality comprises the step of focus assessment processing the image.

According to another aspect of the present invention, the telephone is unlocked if the step of comparing identifies the person.

In a further embodiment within the scope of the present invention, a system of identification of a person for unlocking a telephone comprises a telephone security module, a second memory for storing at least one template of at least one image of an iris of at least one person's eye; and a second processor for comparing the template of the stored iris image with the at least one stored template of the second memory to identify the person, and for unlocking the telephone responsive to the result of the comparison.

In accordance with a further aspect of the present invention, the second memory and second processor are housed in a central station remote from the telephone security module.

In accordance with a further aspect of the present invention, the second processor unlocks the telephone when the template of the stored iris image substantially matches the at least one stored template of the second memory.

In a further embodiment within the scope of the present invention, a telephone security module comprises: iris acquisition means having a front surface for obtaining an image of an iris of an eye; a lens having a image plane disposed in front of the front surface of the iris acquisition means; a mirror disposed on a side of the lens opposite the iris acquisition means; an illuminator disposed along a side of the mirror; a first memory for storing at least one template of at least one image of an iris of at least one person's eye; a second memory for storing an iris image obtained by the iris acquisition means; a processor for extracting a template from the stored iris image; and a comparator for comparing the template from stored iris image with the at least one template to identify the person.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other aspects of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings. For the purpose of illustrating the invention, there is shown in the drawings an embodiment that is presently preferred, it being understood, however, that the invention is not limited to the specific methods and instrumentalities disclosed. In the drawings:

FIG. 1 is a schematic diagram of an exemplary iris imager in accordance with the present invention;

FIG. 2A is a schematic diagram of the imager of FIG. 1 shown in greater detail;

FIG. 2B is a schematic diagram of another exemplary imager in accordance with the present invention;

FIG. 3 is a simplified flowchart of a method of operation in accordance with the present invention;

FIG. 4 is a schematic diagram of an exemplary iris image recognition system in accordance with the present invention;

FIG. 5 is a schematic diagram of an exemplary iris imager having visual and aural indicators in accordance with the present invention;

FIG. 6 is a more detailed flow chart of a method of operation in accordance with the present invention;

FIG. 7 is a schematic diagram of an exemplary iris image recognition system having a focus assessment processor in accordance with the present invention;

FIG. 8 is a schematic diagram of an exemplary iris imager incorporated into a telephone in accordance with the present invention;

FIG. 9 is an isometric view of an exemplary telecommunications iris imager and telephone in accordance with the present invention; and

FIG. 10 is a flow diagram of an exemplary method of operation of a telecommunications iris imager in accordance with the present invention.

## DESCRIPTION OF EXEMPLARY EMBODIMENTS AND BEST MODE

The present invention is directed to a compact, handheld imaging apparatus and method which can be used to capture high-quality iris images. Preferably, the imager has sensors and indicators which assist the human operator in aligning and focusing the device. The imager also automatically captures the image when proper positioning is achieved. Because it is small and compact, it is practical for integration into a cellular telephone where it is used to authenticate telephone subscribers and eliminate cellular telephone fraud. Throughout the following detailed description similar reference numbers refer to similar elements in the figures of the drawings.

FIG. 1 illustrates a preferred embodiment of the handheld imager **100** in accordance with the present invention. The exemplary handheld, non-invasive, non-contacting iris imager comprises iris acquisition means **105**, an imaging lens **110**, a mirror **120**, an optional diopter correction lens **125**, and an illuminator **130**. The imager **100** is preferably powered by a standard DC supply provided by a cellular telephone.

The iris acquisition means **105** is preferably a conventional solid state video camera, such as a charged coupled device (CCD) or complementary metal oxide semiconductor (CMOS) device. A preferred camera is a ⅓ inch format, monochrome CCD board camera, such as Computar Model EM200. Preferably, the video camera **105** is sensitive to light of wavelengths in the range of about 400 nanometers to about 1100 nanometers, and is positioned so that its front surface coincides with the image plane of the lens **110** in front of it. In the preferred embodiment, the object plane of the lens is approximately 89 mm in front of the lens **110**. More preferably, the lens **110** is an optical lens with approximately 14.2 mm focal length.

The mirror **120**, preferably a concave cold mirror having a radius of curvature preferably about 276 mm, is disposed on the side of the lens **110** opposite the video camera **105** and creates a magnified virtual image of the iris behind the mirror **120**. In the preferred embodiment, the mirror **120** reflects visible light with wavelengths in the range of about 400 to about 700 nanometers, and passes light having longer wavelengths, such as those in the range of about 700 to about 900 nanometers.

The illuminator **130** is positioned just outside the edge of the cold mirror **120** and is used to illuminate the iris of the subject being identified. The preferred illuminator **130** emits light having wavelengths of about 680 to about 900 nanometers. Preferably, the illuminator **130** is a miniature quartz halogen or krypton gas bulb operating at approximately 1 watt.

The imager acquires images of an iris with sufficient clarity, focus, and size for use with conventional image processing and comparison routines, preferably in less than about 3 seconds. A preferred image processing and comparison routine is described in U.S. Pat. No. 5,291,560, "Biometric Personal Identification System Based on Iris Analysis", issued to Daugman, and commonly assigned with the present invention to IriScan Inc., and incorporated herein by reference. However, any processing and comparison technique can be used with the image that is acquired at the imager, such as the image pixel correlation technique

described in U.S. Pat. No. 5,572,596, "Automated, Non-Invasive Iris Recognition System and Method", issued to Wildes et al. and the techniques described in U.S. Pat. No. 4,641,349, "Iris Recognition System", issued to Flom et al., both of which are incorporated herein by reference.

FIG. 2A shows the apparatus of FIG. 1 in greater detail. The lens **110** gives a high resolution image of the eye **150** of the user, who is positioned in front of the lens **110**, so that extreme proximity between the eye **150** and the imager **100** is not required (i.e., no contact is needed between the subject and the imager **100**).

The handheld iris imager comprises a solid-state image capture device and an optical system which forms an image **109** of the iris on the image capture device at the image plane of the video camera **105** and at the same time produces a virtual image **115** of the iris which the user can use to position and focus the iris image. As a result, the user can, using the same eye being imaged, see a reflected image of the iris which can be used to position the handheld imager **100** so that a good iris image (i.e., an image that can be processed and compared to those stored in a database) can be obtained.

FIG. 2A also shows an optional dioptric correction lens **125** positioned between the eye **150** and the cold mirror **120**. The dioptric correction lens **125** is an adjustable optical element which corrects for the close-range focusing ability of the individual eye, which varies from subject to subject. When the lens **125** is properly adjusted, the magnified, reflected virtual image **115** of the subject's eye appears in sharp focus to the subject at the same eye-to-mirror distance at which the subject's eye is sharply focused on the front surface of the camera. This simplifies use of the imager, because the subject simply positions the image so that the virtual image **115** of the iris appears sharply focused.

A preferred embodiment of the dioptric correction mechanism has no correction lens **125** and instead has a mechanical means (not shown) for adjusting the position of the cold mirror **120** relative to the camera lens **110**. This allows the user to vary the object distance of the cold mirror **120**, thus changing the eye-to-lens distance at which the virtual image **115** of the iris is sharply focused.

The ability to set the dioptric correction mechanism to accommodate a particular user has a great utility if the imager is used by only one person most of the time. Once the correction is set, the user can easily position the device to obtain a sharply focused reflected image. This automatically produces a sharply focused image from the camera and substantially immediate acceptance of the image by the focus assessment processor described below. Image capture time is thereby reduced and overall convenience and utility is enhanced.

An eye **150** is positioned in front of the imager **100** (e.g., about 3.5 inches in front), as shown in FIG. 2A, and the illuminator **130** is turned on. This, in turn, illuminates the eye **150** and the iris therein. Preferably, the light having wavelengths of about 400 to about 700 nanometers is reflected by the cold mirror **120**, thereby forming a magnified virtual image **115** behind the mirror **120** which the user can see through the eye being imaged. The radius of curvature of the mirror is selected so that the magnified image **115** of the eye substantially fills the user's entire field of view. Hence, when the imager **100** is positioned so that the entire eye **150** is visible, it is virtually assured that the eye **150** will be substantially centered in the object plane **140** of the camera **105**. Under these conditions, the light having wavelengths of about 700 to about 900 nanometers is passed by the mirror **120** and forms an approximately centered image **109** of the eye **150** at the image plane **107** of the camera **105**. The image is then captured and processed, as described below.



Although a cold mirror (one which reflects shorter wavelengths and passes longer wavelengths) is described herein, it is understood that a hot mirror (one which reflects longer wavelengths and passes shorter wavelengths) could also be used in accordance with the present invention. Such a configuration is shown in an imager **101** in FIG. 2B. The eye **150** is illuminated by an illuminator **131** emitting light having wavelengths in the range of about 680 to 900 nanometers. This light is reflected by the eye **150** and the light having wavelengths in the range of about 700 to 900 nanometers is reflected by the hot mirror **121** to be focused by the lens **111** onto the front surface of the camera **106**. Light reflected from the eye **150** having shorter (visible) wavelengths in the range of about 400 to 700 nanometers passes through the hot mirror **121** and strikes a concave broadband mirror **122** which reflects light having wavelength from about 400 to 900 nanometers. This light forms a virtual image **115** of the eye **150** behind the concave mirror **122** that the user can see and use to align and focus the device, as described below.

The imager **100** of FIGS. 1 and 2A, as well as the imager of FIG. 2B, is used in a system to identify the iris image that has been captured. As shown in FIG. 3, the eye is illuminated at step **160**, and an acceptable or suitable image of the iris is obtained at step **165**. The image is processed to extract an iris template or code at step **170**, the template or code is encrypted (optional) and transmitted to the cellular provider (such as a central station; e.g., a Mobile Telephone Switching Office) at step **175**, and the template or code is decrypted (if necessary) and compared to pre-existing templates or codes of authorized subscribers stored in a memory or database for identification and authorization of the user at step **180**. If the user is authorized, the cellular provider enables the call placement at step **185**. The cellular provider can either enable the call at the central station or send a signal to the telephone processor directing it to unlock the telephone.

FIG. 4 is a schematic diagram of an exemplary iris image recognition system in accordance with the present invention. The imager **100** is coupled to a microprocessor **210** that performs the processing and encryption. The microprocessor **210** resides in a cellular telephone **200**.

The microprocessor **210** is coupled to the imager **100** via conventional cables and/or printed circuit boards (PCBs) that are incorporated into the telephone **200**. Other conventional means for coupling the imager **100** and the microprocessor **210** can be employed. The microprocessor **210** controls the imager **100** and runs software held in read only memory (ROM) **205**. The processor **210** is connected via a bus **207** to the ROM **205**, a random access memory (RAM) **232**, another memory such as an erasable programmable ROM (EPROM) **230**, and an input/output (I/O) controller **225**. The RAM **232** is large enough to hold at least one captured image of an iris. The I/O controller **225** is connected to the appropriate circuitry and drivers (not shown) for issuing commands to control the imager **100**.

The imager **100** preferably uses a digital camera and transmits digital images directly to the processing unit **210**. "On/off" data is transmitted from the imager **100** to the processor **210** to initiate the image acquisition function. A digital image could be provided if a digital camera is used.

The image processing consists of a number of image processing steps (such as those described in U.S. Pat. No.

5,291,560 and U.S. Pat. No. 5,572,596, which are herein incorporated by reference) which lead to extraction of a unique and highly specific digital biometric template that can be used to identify the individual based on intensity patterns within the iris. The biometric template is transmitted to the cellular provider where it is compared against other templates stored in a memory or database. The database stores selected data representing images of the iris of a plurality of subjects. A match of the biometric template with a template stored in the database identifies the subject whose iris is being imaged.

Although an image of the eye is reflected back to the subject in mirror **120**, this may not provide the desired feedback to the user to enable the user to properly position the imager so that a suitable iris image is obtained. For example, a user may be a novice in using and positioning the imager **100** with respect to the eye **150**, or the user may be attempting to image the eye of another subject with the imager. Thus, preferably, the imager **100** comprises a passive feedback mechanism to guide the user in positioning the eye **150** to an optimum location to allow acquisition of a suitable image.

The passive feedback mechanism is an indicator or combination of indicators that provides, on a near real-time basis, an indication to the user that an adequate iris image has or has not been obtained. FIG. **5** is a schematic diagram of an exemplary iris image recognition system that includes position indicators in accordance with the present invention. Preferably, the indicator is visible and/or audible, such as, for example, an indicator lamp **305** (e.g., a light emitting diode (LED)) that lights when an acceptable image has been captured (i.e., "image acquired"), and a aural indicator via a speaker **310**, such as a beep or other tone, that sounds periodically until an acceptable image has been captured (i.e., "imaging in progress").

Additional indicators **306**, **307** can be also be used, either alone or in combination, for such indications as "subject identified-accept" and "subject not identified-reject". These indications would be activated pursuant to the results of the processing and comparison performed at the database server at the cellular provider, as described above with respect to FIG. **3**. Alternatively, other display devices, such as liquid crystal displays used for other purposes within the telephone, could be used as indicators.

The imager **100** also preferably has an on/off switch (not shown), such as a pushbutton, for powering up the imager and initiating the image acquisition process. Power for the imager **100** is preferably supplied by a battery. The imager **100** receives and acts on instructions from the processor **210** to perform functions such as lighting or turning off the indicator lamp(s) **305**, providing the audible signals via the speaker **310**, and lighting the 'accept' and 'reject' indicators.

FIG. **6** is a more detailed flow chart of a method of operation in accordance with the present invention. The eye is illuminated at step **350** and an image of the iris is obtained at step **355**. At step **360**, it is determined if the image is suitable for use with the image processing and comparison routines. If the image is suitable, the image is passed to the processor for further processing, at step **370**, and transmission to the cellular provider. A comparison of the template to the templates stored in a database at the cellular provider is performed at step **373**. If the comparison provides a positive match, then authorization is granted at step **376** for the user to use the phone. If the comparison does not provide a positive match, then authorization is not granted for the user to use the phone.



If the image is not suitable at step **360**, then at step **380**, the indicator(s) is activated (e.g., a beep sound is issued), and processing continues at step **355** (i.e., another image is obtained).

Because the eye's own focusing system automatically adjusts to bring the virtual image **115** into sharp focus to the user, it cannot be relied upon to always accurately focus the eye image on the camera **105**. For this purpose, a focus assessment system is used in one embodiment, as shown in FIG. **7**. Digital video image information from the imaging device **100** is stored in a frame buffer memory **410**, such as a RAM similar to RAM **232** described above with respect to FIG. **4**, and capable of storing one complete frame of digitized video information. A focus assessment processor **420** accesses the digitized image information and applies certain measurement algorithms which are disclosed in a co-pending application entitled "Video-Rate Focus Assessment", filed concurrently with this application Ser. No. 60,109,960 Nov. 25, 1998, and incorporated herein by reference. The output of the focus assessment is used to control an indicator, such as the audible indicator **310**. As long as the focus assessment processor **420** determines that the captured image is not acceptable for further processing and comparison, the audible indicator **310** is directed to emit periodic sounds to alert the user. Images are repeatedly acquired and assessed until an acceptable one is received. After an acceptable iris image has been received, the audible indicator **310** is turned off and the final image is retained for further processing and comparison, for example, by the microprocessor **210**, as described above.

Any known technique for image focusing can be used with the imager of the present invention, such as those described in U.S. Pat. No. 4,876,608, entitled "Focus and Signal to Noise Measurement Routines in Input Scanners", issued to Eaton, U.S. Pat. No. 5,151,583, entitled "Focus Adjustment Device Having Restricting Means for Restricting a Selecting Action According to the Degree of Nearness of a Distance Measurement", issued to Tokunaga et al., and U.S. Pat. No. 5,404,163, entitled "In-Focus Detection Method and Method and Apparatus Using the Same for Non Contact Displacement Measurement", issued to Kubo. The preferred system and method for focus assessment is described below.

A focus score is computed for each video frame (i.e., each captured image). If the focus score exceeds a predetermined value, then it is determined that the image is focused enough for further processing and comparison. If the focus score does not exceed the predetermined value, then it is determined that the image is not focused enough for further processing, and an indicator (such as indicator **310**, described with respect to FIG. **5**) is activated and a further image is captured. Alternatively, a sequence of image frames can be obtained that cycle through a range of focus distances strobed at the video frame-rate, and the focus score computed for each frame can enable the selection of the best focused frame within the sequence of frames. For example, by obtaining image frames at each of several different lens settings and then fitting a spline curve to their respective focus scores one can predict the lens position that would deliver substantially the sharpest focus, by setting the derivative of the parameterized spline curve to zero and then solving the equation for position.

Specific implementation features of the preferred focus assessment system and method which enable its real-time operation, include (1) the computation of quantities in the 2D Fourier domain, without needing to compute an actual 2D Fourier Transform of an image (this avoids the need for

approximately 2.25 million floating-point operations required for an FFT (Fast Fourier Transform) on a 500×500 pixel image, as the computational complexity of an FFT on n×n data is $O(n^2 \log_2 n)$); (2) only 6,400 integer multiplications (squarings) are performed, which in turn can be eliminated altogether by using small look-up tables; (3) no floating-point operations are required; (4) computation of focus scores is based upon simple algebraic combinations of pixel values within local closed neighborhoods, repeated across regions of the image; and (5) these operations not only allow the algorithm to execute in real-time, but it also enables a straightforward implementation in simple, low-cost, hardware devices that could be embedded within a digital camera or frame grabber.

Preferably, the focus assessment processor **420** is fast enough to determine a focus score for each frame in a video image stream in less than the time it takes to acquire a new frame (e.g., approximately 25 ms). The frame-by-frame focus scores can be used to control a moving lens element for rapid and accurate focus control, or alternatively, to select which of several frames in a video stream is the one in best focus. The rapid selection of well-focused video frames for further processing, such as image analysis and pattern recognition, is important in real-time computer vision because it prevents wasting processing time on poorly-focused images.

The preferred focus assessment processor measures the focus quality of video images at standard rates of 25 (PAL) or 30 (NTSC) frames per second.

It is contemplated that the focus assessment processor **420** can be implemented in a general purpose personal computer (PC) or by a dedicated, low cost processor which is small enough to be incorporated into the camera electronics.

The processing of a video frame results in the return of an integer value (on a scale between 0 and 100) reflecting the quality of focus; the larger the value of the integer, the better the focus. A value of 0 indicates a completely defocused image whereas the value of 100 indicates maximum focus quality. A predetermined threshold is used to determine whether an image is sufficiently focused or whether another image needs to be retrieved. For example, values greater than about 40 can indicate sufficient quality of focus to warrant further image processing, while values less than about 40 cause a new image frame to be grabbed, and optional feedback provided to the focusing mechanism, if one exists, or to the subject controlling the camera position (via the indicator **310**, for example).

Optical defocus is a phenomenon of the 2D Fourier domain. An image represented as a 2D function of the real plane, I(x,y), has a 2D Fourier Transform $F(\mu,\nu)$ defamed as shown in equation 1.

$$F(\mu, \nu) = \frac{1}{(2\pi)^2} \int_x \int_y I(x, y) e^{i(\mu x + \nu y)} \, dx \, dy \tag{1}$$

In the image domain, defocus is preferably represented as convolution by the 2D point-spread function of the defocused optics. This in turn may be modeled as a Gaussian whose space constant is proportional to the degree of defocus. Thus, for perfectly focused optics, the optical point-spread function shrinks almost to a delta function, and convolution with a delta function causes no change to the image. Progressively defocused optics equates to convolving with a wider and wider point-spread function, which averages together whole neighborhoods of pixels by such a weighting function, thereby producing an increasingly blurred image.

If the convolving optical point-spread function causing defocus is modeled as a Gaussian whose width represents the degree of defocus, then defocus is equivalent to multiplying the 2D Fourier Transform of a perfectly focused image with the 2D Fourier Transform of the "defocusing" (convolving) Gaussian. This latter quantity is itself just another 2D Gaussian but in the Fourier domain, and its space constant (σ) there is the reciprocal of that of the image-domain convolving Gaussian that represented the optical point-spread function. The preferred focus assessment processor uses (1) the duality of convolution and multiplication in the two domains; (2) the fact that a Gaussian has a Fourier Transform which is itself a Gaussian, but with the reciprocal width because of (3) the Similarity Theorem. Thus, the 2D Fourier Transform $D_\sigma(\mu,\nu)$ of an image defocused to degree a is related to $F(\mu,\nu)$, the 2D Fourier Transform of the corresponding in-focus image, as given by equation 2.

$$D_\sigma(\mu, \nu) = e^{-\left(\frac{\mu^2+\nu^2}{\sigma^2}\right)} F(\mu, \nu) \tag{2}$$

From the above equation, the effect of defocus is to attenuate primarily the highest frequencies in the image, and that lower frequency components are virtually unaffected by defocus since the exponential term approaches unity as the frequencies $(\mu,\nu)$ become small. For simplicity, the present description has assumed isotropic optics and isotropic blur, and the optical point-spread function has been described as a Gaussian. However, the analysis can readily be generalized to non-Gaussian and to anisotropic optical point-spread functions.

Thus, an effective way to estimate the quality of focus of an image is to measure its total amount of energy in the 2D Fourier domain at high spatial frequencies, since these are the most attenuated by defocus. One may also perform a kind of "contrast normalization" to make such a spectrally-based focus measure independent of image content, by comparing the ratio of energy in the highest frequency bands to that in slightly lower frequency bands. Such spectrally-based energy measurements are facilitated by exploiting Lord Rayleigh's theorem for conserved total power in the two domains, shown in equation 3.

$$\int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} |I(x, y)|^2 \, dx \, dy = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} |F(\mu, \nu)|^2 \, d\mu \, d\nu \tag{3}$$

Thus, high-pass filtering or band-pass filtering an image at a ring of high spatial frequency (using only convolution in the 2D image domain) and measuring the residual energy, is equivalent to making the corresponding energy measurement in the high frequency bands of the 2D Fourier domain. The appropriate measurements in the 2D Fourier domain to assess focus can be performed without computing a time-consuming 2D Fourier Transform. Indeed, the measurements can be performed without even a single floating-point operation, and even without any multiplications if appropriate convolution kernels and look-up tables are used.

A real-time procedure for focus assessment based on these theoretical principles is used in the focus assessment processor **420**. It executes much faster than the video frame-rate, and so real-time focus assessments can be made on a frame-by-frame basis. These can be used either to control the position of a focusing lens element, or alternatively as a type of autofocus system in which frames are grabbed at a variety of focal depths in order to select only the best one for processing, or to prevent time being wasted on processing image frames which are assessed to be in poor focus.

The 2D spectral measurements described above can be implemented by convolving an image with the following convolution kernel, in which pixel values within a predetermined region, such as, for example, an (8×8) neighborhood, are added together with the weights indicated in each of the cells:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| −1 | −1 | −1 | −1 | −1 | −1 | −1 | −1 |
| −1 | −1 | −1 | −1 | −1 | −1 | −1 | −1 |
| −1 | −1 | +3 | +3 | +3 | +3 | −1 | −1 |
| −1 | −1 | +3 | +3 | +3 | +3 | −1 | −1 |
| −1 | −1 | +3 | +3 | +3 | +3 | −1 | −1 |
| −1 | −1 | +3 | +3 | +3 | +3 | −1 | −1 |
| −1 | −1 | −1 | −1 | −1 | −1 | −1 | −1 |
| −1 | −1 | −1 | −1 | −1 | −1 | −1 | −1 |

It should be noted that no pixel-by-pixel multiplications are needed in order to impose these weights. Rather, the pixels in the central region are added together, such as the (4×4) square, that sum is tripled, and then all pixel values in the outer two pairs of rows and columns are subtracted from the tripled sum. The result is squared and added to an accumulator, thus implementing the left-hand side of equation (3) above for this local region of the image. The complete (8×8) convolution kernel is then moved to a new position in the image, along a sampling grid that selects every 4th row and every 4th column, and the operation is repeated. Thus, to assess the quality of focus within the central (320×320) region of an image, this set of 64 pixel summations followed by a squaring operation is repeated a total of $(320/4)^2=6{,}400$ times.

In the 2D Fourier domain, the spectral consequences of this operation can be appreciated by examining the 2D Fourier Transform of the convolution kernel above. The kernel is equivalent to the superposition of two centered square box functions, one of size (8×8) and amplitude −1, and the other of size (4×4) and amplitude +4 (for the central region in which they overlap, the two therefore sum to +3). The 2D Fourier Transform of each of these square functions is a 2D "sinc" function, whose size parameters differ by a factor of two in each of the dimensions and whose amplitudes are equal but opposite, because the two component boxes have equal but opposite volumes. Thus, the overall kernel has a 2D Fourier Transform $K(\mu,v)$ which is the difference of two differently-sized 2D sinc functions, as given by equation 4.

$$K(\mu, \nu) = \frac{\sin(\mu)\sin(\nu)}{\pi^2\mu\nu} - \frac{\sin(2\mu)\sin(2\nu)}{4\pi^2\mu\nu} \tag{4}$$

This is a high-pass (or ultimately a band-pass) filter, selecting only a high range of spatial frequencies in all orientations. Towards its center, corresponding to very low spatial frequencies, its value approaches zero (as can also be inferred from the fact that the sum of all pixel weights in the convolution kernel shown above is zero). Thus, low frequencies play little or no role in computing a focus score, and only relatively high frequencies contribute significantly to the computation of a focus score. Equation (3) shows that summing the squares of all the local convolution sums across the image is equivalent to summing the total amount of high frequency energy in the 2D Fourier Transform of the image. The action of the convolution kernel is to impose the above power spectral weighting function so that primarily high frequency energy is measured.

Finally, the summated 2D spectral energy is passed through a compressive nonlinearity of the form $f(x)=100\, x^2/(x^2+c^2)$ in order to generate a normalized focus score in the range of 0 to 100 for any image.



The focus assessment technique is applied immediately after each image frame is digitized and stored in the frame buffer memory **410** in order to assess whether the focus quality is sufficient to warrant any further processing. If the calculated focus quality value of the captured image is greater than or equal to a predetermined value, the image is passed to applicable programs for further processing, for example for extraction of a biometric template. The focus assessment technique can be used to compare the relative focus of an entire series of images in order to select the one most in-focus (i.e. having the highest focus assessment score), as well as to measure a single image.

The focus assessment technique can be used to provide a feedback indication to a system user who controls the position of the imager relative to the object being imaged. This can be accomplished by activating an indicator which would continue, while successive images are captured and their focus assessed, until the focus assessment score exceeds a predetermined value. At this point, the indicator is deactivated and the last image captured is transferred to the image processor **210** where it is processed to extract the biometric template.

The application of the focus assessment technique in combination with the feedback indicator helps resolve the man-machine interface problems associated with the use of digital imaging devices on the eye. Individuals using the system are provided positive, objective indicators and feedback as to the quality of image focus. The focus assessment processor can also be used in any situation where it is required to determine the quality of focus of video images at industry standard frame rates (NTSC and PAL).

Thus, the image is obtained at the imager and transmitted to an analog to digital converter **405**. The digitized video information is then stored in a frame buffer memory **410**. The focus assessment processor **420** isolates the central 320×320 region of the image. 8×8 pixel blocks (each pixel is in only one block) are then processed by first summing pixels in the central 4×4 region, tripling that sum, and then subtracting from this value all the pixel values in the outer two pairs of rows and columns. This result is then squared. This process is performed on each 8×8 block, and the results are summed. After the entire image has been processed, the summed result is compressed nonlinearly to generate a focus score between 0 and 100. This score is then compared to a predetermined number for determining if the indicator **310** should be activated.

The focus assessment is preferably performed by the microprocessor **210**, or it can be a separate processor element within the telephone.

It is contemplated that in addition to the focus assessment processor, an auto-focus lens system could be used in the present invention. The results of the focus assessment control the lens system, thereby automatically adjusting focus to produce an optimal image. This would place less of a premium on the accuracy with which the user positions the eye, and would be helpful if the user could not see or hear the indicators described above.

The iris imager of the present invention can be used as a security module for electronic devices such as a telephone. FIG. **8** is a schematic diagram of an exemplary iris imager incorporated into a telephone in accordance with the present invention. The imager **700** comprises the camera **105**, lens **110**, mirror **120**, and illuminator **130**, as described above with respect to FIG. **1**. The imager **700** also comprises visible indicators **555**, **556**, **557**, which are similar to indi-

cators **305**, **306**, **307**, respectively, described above with respect to FIG. **5**. An audible indicator **560**, similar to indicator **310**, is also disposed within the imager **700**. The imager **700** further comprises electronics and circuitry **500** for processing and comparing the obtained image. The electronics and circuitry **500** comprises a microprocessor **510** (similar to microprocessor **210**) that controls the imager **700** along with an I/O controller **525** and runs software held in a ROM **505**. The processor **510** is connected to the ROM **505**, a RAM **532** that is capable of storing at least one captured image or an iris, another memory **530**, such as an EPROM, for storing a plurality of biometric templates or iris images that are to be compared with the captured iris image. The electronics and circuitry **500** is also connected to the camera **105**, the illuminator **130**, and the indicators **555**, **556**, **557**, **560** for controlling these elements of the imager **700**. The processor can also comprise a focus assessment processor, similar to the focus assessment processor **420**.

It should be noted that in the embodiment of FIG. **8**, the database memory **530** of templates is stored within the imager **700** and not at a central station (as described, for example, with respect to FIG. **4**), as is the processor **510** used in the comparison. In the embodiment of FIG. **8**, the comparison of the captured image template with the stored templates takes place locally within the telephone, and no data is sent to the central station for comparison or authentication.

The imager **700** is coupled to telephone electronics **570** for transmitting encrypted or unencrypted data to another telephone or system via an antenna. The telephone electronics **570** is essentially a telephone and is preferably a conventional cell phone having telephone electronics and is connected to a transmission antenna. Preferably, a conventional voltage regulator (not shown) provides the appropriate operating voltage to the imager **700** from the power supply (e.g., a battery) of the phone.

Preferably, the imager **700** of the present invention is incorporated into a handset of a telephone **575**, as shown in FIG. **9**. The present invention can be incorporated into a conventional digital cell phone, as shown in FIG. **9**, such as those manufactured by Qualcomm.

FIG. **10** is a flow diagram of an exemplary method of operation of a telecommunications iris imager in accordance with the present invention. A user desiring to make a telephone call first unlocks the telephone by having his iris identified by the imager residing within the phone. The eye, and thus the iris, is illuminated at step **605**. An image is obtained of the iris at step **610**. At step **615**, it is determined if the image is suitable for further processing and comparison, as described above. If the image is not suitable, the appropriate indicators are activated at step **620**, and processing returns to step **610** with the capture of another iris image.

If the captured image is suitable for further processing, the image is processed at step **630** (an indicator can be activated to alert the user that a suitable image has been captured) and is compared to the stored images residing in a database, for example, in a memory, at step **635**. If there is no match between the captured image and the stored images, at step **640**, the appropriate indicators are activated at step **645**, and the imaging routine exits. In this manner, the telephone remains locked, and cannot be used because it is determined that the user is unauthorized.

If there is a match between the captured image and the stored images, at step **640**, the phone is unlocked (and an indicator can be activated) at step **650**, and the user is then able to use the phone to place a call, for example. The phone can be returned to its locked, secure state either upon being powered down or upon completion of the phone call.

Although illustrated and described herein with reference to certain specific embodiments, it will be understood by those skilled in the art that the invention is not limited to the embodiments specifically disclosed herein. Those skilled in the art also will appreciate that many other variations of the specific embodiments described herein are intended to be within the scope of the invention as defined by the following claims.

What is claimed is:

**1**. A telephone security module comprising:

iris acquisition means having a front surface for obtaining an image of an iris of an eye;

a lens having a image plane disposed in front of said front surface of said iris acquisition means;

a mirror disposed on a side of said lens opposite said iris acquisition means;

an illuminator disposed along a side of said mirror;

a memory for storing an iris image obtained by said iris acquisition means;

a processor for extracting a template from said stored iris image; and

a communications interface for transmitting said template to a central station.

**2**. The telephone security module according to claim **1**, wherein said iris acquisition means comprises a camera, and said mirror is a cold mirror.

**3**. The telephone security module according to claim **2**, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

**4**. The telephone security module according to claim **2**, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

**5**. The telephone security module according to claim **1**, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

**6**. The telephone security module according to claim **1**, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

**7**. The telephone security module according to claim **6**, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

**8**. The telephone security module according to claim **1**, wherein said processor unlocks a telephone responsive a signal received from said central station.

**9**. A system of identification of a person for unlocking a telephone, comprising:

the telephone security module of claim **1**;

a second memory for storing at least one template of at least one image of an iris of at least one person's eye; and

a second processor for comparing said template of said stored iris image with said at least one stored template of said second memory to identify the person, and for unlocking the telephone responsive to the result of said comparison.

**10**. The system according to claim **9**, wherein said second memory and said second processor are housed in a central station remote from the telephone security module.

11. The system according to claim 9, wherein said second processor unlocks the telephone when said template of said stored iris image substantially matches said at least one stored template of said second memory.

12. A telephone security module comprising:

iris acquisition means having a front surface for obtaining an image of an iris of an eye;

a lens having a image plane disposed in front of said front surface of said iris acquisition means;

a mirror disposed on a side of said lens opposite said iris acquisition means;

an illuminator disposed along a side of said mirror;

a first memory for storing at least one template of at least one image of an iris of at least one person's eye;

a second memory for storing an iris image obtained by said iris acquisition means;

a processor for extracting a template from said stored iris image; and

a comparator for comparing said template from stored iris image with said at least one template to identify the person.

13. The telephone security module according to claim 12, wherein said iris acquisition means comprises a camera, and said mirror is a cold mirror.

14. The telephone security module according to claim 13, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

15. The telephone security module according to claim 13, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

16. The telephone security module according to claim 12, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

17. The telephone security module according to claim 12, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

18. The telephone security module according to claim 17, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

19. The telephone security module according to claim 12, wherein said processor unlocks a telephone responsive to the results of said comparison.

20. A telephone security module comprising:

a camera having a front surface for obtaining an image of an iris of an eye;

a lens having a image plane disposed in front of said front surface of said camera;

a concave cold mirror disposed on a side of said lens opposite said camera;

an illuminator disposed along a side of said mirror;

a memory for storing an iris image obtained by said camera;

a processor for extracting a template from said stored iris image; and

a communications interface for transmitting said template to a central station.

21. The telephone security module according to claim 20, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

22. The telephone security module according to claim 20, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

23. The telephone security module according to claim 20, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

24. The telephone security module according to claim 20, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

25. The telephone security module according to claim 24, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

26. The telephone security module according to claim 20, wherein said processor unlocks a telephone responsive a signal received from said central station.

27. A telephone security module comprising:

a camera having a front surface for obtaining an image of an iris of an eye;

a lens having a image plane disposed in front of said front surface of said camera;

a concave cold mirror disposed on a side of said lens opposite said camera;

an illuminator disposed along a side of said mirror;

a first memory for storing at least one template of at least one image of an iris of at least one person's eye;

a second memory for storing an iris image obtained by said camera;

a processor for extracting a template from said stored iris image; and

a comparator for comparing said template from stored iris image with said at least one template to identify the person.

28. The telephone security module according to claim 27, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

29. The telephone security module according to claim 27, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

30. The telephone security module according to claim 27, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

31. The telephone security module according to claim 27, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

32. The telephone security module according to claim 31, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

33. The telephone security module according to claim 27, wherein said processor unlocks a telephone responsive to the results of said comparison.

* * * * *